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Effectiveness of sloping agricultural land technology on soil fertility status of mid-hills in Nepal

Kiran Lamichhane

Abstract: Hedgerows with intercropping systems were established at the ICIMOD test and demonstration site at Godawari to assess the effectiveness of Sloping Agricultural Land Technology (SALT) in reducing runoff water volume, controlling soil loss, increasing crop production, and improving soil fertility in the mid-hills of Nepal. Runoff water volume (1996–2002), soil loss (1996–2002) and maize yield (1995–2001), and soil fertility-related parameters were assessed on SALT models with three factors: the type of nitrogen-fixing plant, the farmers' practice, and fertilizer use. Results showed a significant effect of Alnus nepalensis and/or Indigofera dosua on runoff water volume, soil loss, crop production, soil water retention, and soil nutrients (NPK). Farmers' practice and fertilization did not play a significant role in reducing runoff water and soil loss. However, farmers' practice significantly increased crop production. Therefore, integrating soil conservation approaches on SALT systems enhances stable economic output to hills and mountain farmers.

Key words: Sloping Agricultural Land Technology; hedgerows; agro forestry; mountain farming system; soil erosion; soil nutrient

Introduction

Soil erosion, land degradation, and crop production are intertwined with climate change in hill and mountain regions, and pose threats to sustainable agriculture (Sun et al. 2008; Bhattarai et al. 2009; Manandhar et al. 2011). Nepal, with an agrarian economy, has more than 50% of the country's population inhabiting hills and mountains (Central Bureau of Statistics, CBS-Nepal 2008), and more than 86% of Nepal's landscape consists of hills and mountains (Pratap 1998). Agriculture is the mainstay of the country economy and 80% of the population practices subsistence farming (CBS 2008). Cultivation on sloping land is common in Nepalese highland agriculture and leads to soil erosion due to lack of soil conservation practices. This farming system has not yielded enough food to meet the demand of a growing population, due in part to low agricultural productivity (Sharma et al. 2010; Chhetri 2011). The nexus between rural poverty and resource degradation intensified challenges to achievement of sustainable agriculture since mountain ecosystems are sensitive, fragile, and vulnerable to soil and nutrient loss (Scherr 2000; Chettri et al. 2007; Gabet et al. 2008; Scherr and McNeely 2008; Taylor et al. 2010; Farrell et al. 2011; Sudmeier-Rieux et al. 2011).

Studies of soil loss in Nepal showed that surface erosion in agricultural land in hills and mountain varied from 2–105 $Mg \cdot ha^{-1} \cdot a^{-1}$ (Chhetri 2011). Soil loss from agricultural lands in the hills not only caused reduced agricultural production but also jeopardized the function of hill ecosystems, both of which are common problems with subsistence mountain farming system reported elsewhere (Scherr 2000; Gabet et al. 2008; Chhetri 2011; Lenka et al. 2012). In a mountainous country like Nepal, soil erosion has always been a major constraint on a sustainable agriculture system (Sharma et al. 2010; Upadhyay et al. 2011). The lack of a sustainable agriculture system results in severe on- and off-site environmental, economical, and social impacts.

Resource conservation technologies such as agroforestry, terrace farming, hedgerow intercropping, and Sloping Agricultural Land Technology (SALT) can reduce soil loss and increase food production. For instance, among several available resource conservation technologies, SALT is an integrated approach for soil conservation and food production in a region with sloping lands (Evans 1998; Pratap 1998; Tacio 1998; Grogan et al. 2012). Under SALT, hedgerows, a major feature of the system, are planted along the contours of sloping land at intervals of four to six meters in double rows, and various cereal crops and perennial cash crops are cultivated in the alleys. Hedgerows are planted using locally available nitrogen-fixing shrubs and trees that act as effective barriers to soil erosion, and thus conserve soil moisture.

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When a hedge grows to 1.5 to 2 m tall, it is pruned down to about 40 cm. Pruning not only reduces crop shading effects, but the pruning waste is used as green manure or for compost (Sun et al. 2008). In comparison to conventional slope farming, SALT conserves soil and water, enriches soil, stabilizes slopes, enables farming on slopes and gradually forms bio-terraces (Grogan et al. 2012). Narrow strips of hedge help to form bio-terraces by diffusing the concentrated flow of runoff water and protecting soil and crops from wind erosion, thereby ameliorating soil fertility. SALT systems help considerably to improve the function of hill farming ecosystems (Tacio 1998). The following are the four different SALT models based on land use: **SALT-1,** Sloping Agricultural Land Technology, which has a land use ratio of 3:1 for agriculture and forestry; **SALT-2,** Simple Agro-Livestock Technology, which has a land use ratio of 2:2:1 for agriculture, livestock, and forestry; **SALT-3,** Sustainable Agroforest Land Technology, which converts non-productive marginal land into economically productive land to supplement production from other SALT models with a land use ratio of 2:3 for agriculture and forestry; and **SALT-4,** Simple Agrofruit Livelihood Technology, which focuses on developing orchard and horticulture, and planting crop-based systems with a land use ratio of 2:2:1 for agriculture, horticulture, and forestry (Tacio 1998). These SALT models are related to each other based on types of N-fixing plant, crop, horticulture, farmers' practice and external fertilizer use.

The fate and turnover of dissolved organic nitrogen play important roles in ecosystem function (Farrell et al. 2011). Soil nutrients increased significantly in degraded land through improved farming activities in the Chittagong hills (Biswas et al. 2010). Soil organic matter (SOM) plays a dominant role in nitrogen supply, and, to a lesser extent in phosphorus supply. Lenka et al. (2012) reported a significant increase in SOM, soil carbon, and soil moisture retention six years after establishing N-fixing plants, whereas SOM doubled. Higher SOM levels improve infiltration and water holding capacity, which reduces surface runoff and soil erosion. SOM can ameliorate the negative effects of low pH as well as problems caused by having too coarse or too fine a soil texture. N-fixing legume trees with intercropping cereals and inorganic fertilizer increase maize productivity (Maskey 2003; Chhetri 2011). As the SOM content in soil increases, the nitrogen and phosphorus content also increase as they are important constituents of organic matter (Taylor et al. 2010). The hedgerows of N-fixing plants are pruned several times a year and provide large amounts of fresh green manure and mulch material. This nitrogen rich foliage mobilizes C:N ratios through soil thus improving soil fertility (Bhattarai et al. 2009; Upadhyay et al. 2011). Hedgerows also develop deep root systems that may take up leached and available potassium from subsurface soil below the root systems of crops. Kareemulla and Rao (2012) showed that ill effects of climate change in degrading crop productivity are potential threats to mountain soil nutrients. Gami et al. (2009) found application of farm-yard manure significantly increased the soil organic carbon and total nitrogen stocks substantially for longer periods. Soil phosphorus can be recovered by leguminous crops and N-fixing hedges in low-nutrient environments (Nandwa et al. 2011). Chettri et al. (2007) reported on develop-

ment of forested conservation corridors at the landscape scale that serve as a basis of economic growth to mountain people through integrative soil and vegetation management practices.

Research and technology development in Nepal have been inadequate to enhance sustainable agricultural production. The government of Nepal emphasized developing SALT models at suitable watershed areas in the Tenth Plan (National Planning Commission 2003–2007). However, limited studies have been carried out to assess the effectiveness of SALT system over long periods. The resulting lack of data has hindered policy decision making processes. The present study aimed to evaluate the effectiveness of SALT systems in relation to three major variables (N-fixing plants, farmers' practice and fertilizer input) to minimize runoff water, reduce soil erosion, improve soil nutrients, and increase maize productivity on sloping lands in the mid-hills of central Nepal.

Materials and methods

Study site

The experiment was conducted in the mid-hills nearly 15 km southeast of Kathmandu. The Integrated Centre for Mountain Development (ICIMOD) has developed a test and demonstration site on 30 ha of sloping forest and shrub land at Godawari (27°36′ N, 85°24′ E, alt. 1550–1800 m a.s.l., slope 5° to 60°), which lies in the northwest foothills of Phulchoki Mountain in the Godawari Village Development Committee (VDC) area, Lalitpur district. Traditional farming practices and various SALT models have been demonstrated in an approximately 1500 m^2 area to monitor and record data on runoff water volume, soil loss, and crop production.

The climate in the study area ranges from subtropical to warm temperate with average annual rainfall of 2,000 mm with most of the annual rainfall received during monsoons (June – September). The site has a mean annual temperature of 16.6°C with a minimum in January (−1.7°C) and a maximum in May (33.9°C) (ICIMOD 2004).

Experimental design

The study started in 1995 with three replications for each of five treatments, and it ran for seven years. Each treatment plot was a rectangle 20 m along the slope and 5 m across the slope (Table 1). In each plot, five rows of N-fixing hedgerows were planted at four-meter intervals except in the control area. These plots were separated by iron sheets. Runoff water volume and soil sediment were collected in a tank at the bottom of each plot.

The water level in each tank was recorded after every rainfall event to estimate runoff. Sediment was thoroughly homogenized and 0.5 L was collected if the water level in the tank exceeded 10 cm. All tanks were emptied and cleaned after precipitation event. The sediment samples were filtered and oven dried at 70°C for 24 hours. The sediment in the filter paper was weighed and soil loss for every rainfall event was calculated for each plot. In all

treatments, external fertilizer was added seasonally except for T3, and maize was grown and harvested in the summer season only except for T5.

Table 1. Combination of treatments in this study

Treatments	Control/Plant	Farmers Practice	Fertilizer
T1	Control	+	+
T2	*Alnus nepalensis*	+	+
T3	*Alnus nepalensis*	+	−
T4	*Indigofera dosua*	+	+
T5	*Alnus nepalensis*	−	+

The experiment was designed to determine whether N-fixing plants with or without fertilizer reduce runoff and soil loss, and improve soil properties and crop yield. For example, I compared T1, T2 and T4, each having both farming and fertilizer, to test for differences caused by the hedgerow plant species (*A. nepalensis* or *I. dosua*).

Three variables were studied for their effect on various aspects of soil conservation and food production (Table 1). Factor 1 (species of hedgerow plant) was set at three levels: 1, control or no plant; 2, *Alnus nepalensis*; 3, *Indigofera dosua*. Factor 2 (farmers' practice) was either present or absent. Factor 3 (fertilizer) was also set at two levels, applied or not applied. The levels of the factors were not fully crossed and this compromised the conclusions derived from the results. Whereas a total of 12 combinations of treatments ($3 \times 2 \times 2$ for the three factors) were required for proper data analysis, there were only five combinations of treatments. Therefore, the effect of each treatment could not be quantified independent of other treatments so the inferences and conclusions have been drawn with care.

Soil sampling and chemical analysis

Soil samples were studied for only one year. Two soil samples were collected from each replicate at 10–15 cm in early monsoon (10 June 2004). Soil parameters related to soil fertility were analyzed at the Central Department of Environmental Science, Tribhuvan University, Kathmandu. OM (Walkley and Black method), N (micro-Kjeldhal unit), available P_2O_5 (Modified Olsen bicarbonate method) and available K_2O ammonium acetate method (flame photometer), pH (pH meter), texture (hydrometric method), water holding capacity, and moisture content were analyzed as described by Zobel et al. (1987). Data on runoff water volume and soil loss (1996–2002), and maize yield (1995–2001) were officially provided by the ICIMOD Godawari Test and Demonstration site.

Statistical analysis

Data analyses were run on SAS 9.2 (SAS Institute, NC, USA). Normality and homogeneity for all the variables of study parameters were performed by Shapiro–Wilk's normality test. Two-way ANOVAs with Student–Newman–Keuls (SNK) multiple range tests were calculated to quantify differences between treatments in water runoff water volume, soil loss, and maize

production. A one-way ANOVA was conducted to independently analyze the effect of farmers' practice (T2 and T3) and fertilizer (T2 and T5). For soil nutrients, a one-way ANOVA with pairwise comparison was used to test differences in treatment at three levels of analysis (T1, T2 and T4). When parametric assumptions for normality were not met, the non-parametric Kruskal–Wallis test was conducted. In all tests, significance level was set at $\alpha = 0.05$. Variables were annual runoff water volume ($m^3 \cdot ha^{-1}$), annual soil loss ($Mg \cdot ha^{-1}$), maize yield ($kg \cdot ha^{-1}$), soil parameters (moisture content %, water holding capacity %, pH, soil texture) and soil nutrients (organic matter %, total nitrogen %, available P_2O_5 $kg \cdot ha^{-1}$, available K_2O $kg \cdot ha^{-1}$). GraphPad Prism 5 software was used for graphical representation.

Results and discussion

Effects of SALT models on runoff water volume

Treatments T1, T2 and T4 were similar in the presence of farming and fertilizer, but they differed in the type of plant (T1 = control, T2 = *Alnus nepalensis* and T4 = *Indigofera dosua*). Therefore, any observed difference between treatments was attributed to the effect of hedgerow plant species. A two-way ANOVA test showed an overall significant effect of treatments (T1, T2 and T4) on runoff water volume ($p < 0.0001$) (Table 2). A significant difference was also observed across years indicating natural variability in runoff caused by amount of precipitation ($p < 0.0001$). Pairwise comparison of treatments indicated that T2 and T4 reduced runoff in six of the seven study years (Fig. 1, Student–Newman–Keuls (SNK) multiple range test).

Table 2. Influence of N-fixing plants on run-off water volume. Two-way ANOVA results with interaction for combinations of all levels of two main factors: treatment (T1, T2 and T4) and year (1996–2002).

Overall model $F_{20, 42} = 20.32$, $p < 0.0001$, MSE = 112.7				
Source	DF	ANOVA MS	*F* Value	Pr *F*
Year	6	513334.0	40.40	<0.0001
Treatment	2	736681.3	57.98	<0.0001
Year × Treatment	12	50950.4	4.01	0.0004

Runoff water volume was significantly influenced by the interaction between year and treatment ($p = 0.0004$), indicating that the temporal pattern in runoff was not similar in the three treatments. This meant that the trend of increased difference in runoff of T1 versus T2 and T4 together over the study period (see Fig. 1) was statistically significant. This indicated that the effect of plant species on runoff increased with time, probably due to progressive maturation of the hedgerows planted in 1995 and their increasing capacity to control runoff.

N-fixing plants had significant impact in controlling runoff volume when farming and fertilizer were present (T2 versus T4). These plants controlled runoff water by providing cover to the exposed soil and fertilizers. There was no significant difference between *Alnus* and *Indigofera* on runoff volume. However, the effect of plant species was observed in the presence of farming

and fertilizer. The annual average runoff water volume was quite erratic which might be due to uneven rainfall and soil texture. However, the effectiveness of SALT systems T2 and T4 in reducing the runoff water steadily increased by 28%–56% from 1997 to 2002 compared to the control. Similar results were also observed at Chitwan, Paireni where three years after contour hedgerow establishment, runoff declined by 26%–60% over the non-SALT plots (Maskey 2003). Thus, the efficiency of hedgerows in reducing runoff water volume increased with time. Grogan et al. (2012) showed that N-fixing plants promote soil fertility by preventing nutrient and particulate losses in uplands.
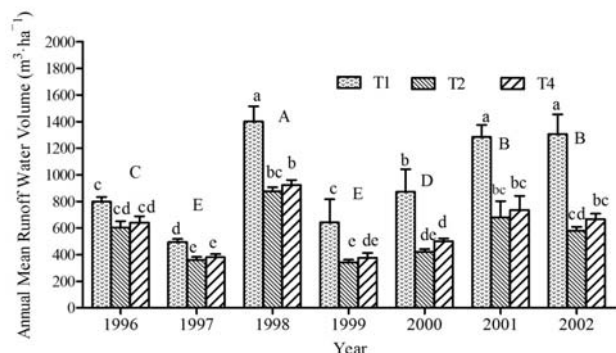

Fig. 1 Effect of N-fixing plants with farming and fertilizer on run-off water volume (Mean ± SE, m^3·ha^{-1}, n = 21) during 1996–2002. Letters "a", "b", "c", "d" and "e" indicate statistically significant differences among treatments T1, T2 and T4. Letters "A", "B", "C", "D" and "E" indicate statistically significant differences among years (Two-way ANOVA, $F_{20, 42}$ = 1.27, p <0.0001, SNK multiple range test, α = 0.05).

Treatments T2 and T3 were similar in the presence of farmer's practice and the type of N-fixing plant (*Alnus*) but the treatments differed in fertilizer input: fertilizer was added to T2 but not T3. Fertilizer application reduced runoff water volume but the effect was not significant (Table 3A). This result might also have been due to the natural variability of precipitation.

Table 3. Influence of (A) fertilizer input (T2 and T3) and (B) farmers' practice (T2 and T5) on runoff water volume (One-way ANOVA results, 1996 – 2001).

Treatment	df, *F* value	Pr *F*
A. Effects of fertilizer (T2 and T3)	$F_{0.05 (1), 1, 40}$ = 3.9	0.055
B. Effects of farmers practice (T2 and T5)	$F_{0.05 (1), 1, 40}$ = 0.0	0.978

Treatments T2 and T5 were similar in plant species (*A. nepalensis*) and fertilizer input, but they differed in farmers' practice, which was present at T2 but absent at T5. There was no significant effect of farmers practice on runoff water volume (see Table 3B) between T2 and T5, indicating that farmers' usual practice of pruning N-fixing plants to plough fields did not make any difference.

Effects of SALT models on soil loss

Overall, a highly significant effect of treatments (T1, T2 and T4) was observed on soil loss (p <0.0001) (Table 4). Significant difference resulted from presence versus absence of *Alnus* or *Indigofera*. A significant effect was also observed across years indicating that temporal differences in soil loss were created by runoff water volume (p <0.0001). Pairwise comparison of treatments indicated that T2 and T4 reduced soil loss in four of the seven studied years (Fig. 2), and pairwise comparison of years indicates the years that were significantly different in soil loss.

Table 4. Influence of N-fixing plants on soil loss. Two-way ANOVA results with interaction for combinations of all levels of two main factors, treatment (T1, T2, and T4) and year (1996–2002).

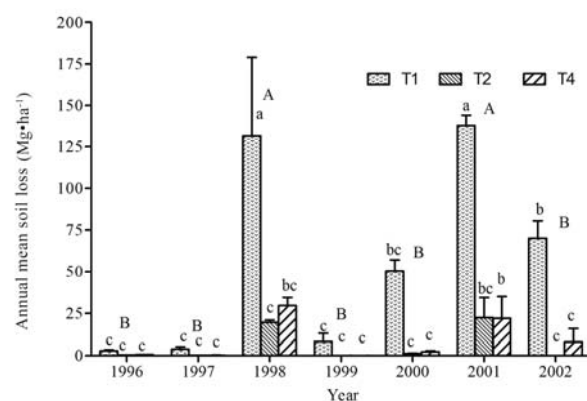| Overall model $F_{20, 42}$ = 12.89, p < 0.0001, MSE = 19.8			
Source	DF	ANOVA MS	*F* Value	Pr *F*
Year	6	6577.5	16.74	<0.0001
Treatment	2	17268.9	43.94	<0.0001
Year × Treatment	12	2273.5	5.79	<0.0001

Fig. 2 Effect of N-fixing plants on soil loss when farmer practice and fertilizer were present (Mean ± SE, Mg·ha^{-1}, n = 21) during 1996–2002. Letters "a", "b" and "c" indicate statistically significant differences among treatments T1, T2 and T4. Letters "A" and "B" indicate statistically significant differences among years (Two-way ANOVA, $F_{20, 42}$ = 12.89, p <0.0001, SNK multiple range test, α = 0.05).

Soil loss was strongly influenced by the interaction of year and treatment (p <0.0001), indicating that temporal trends in soil loss was not similar in the three treatments. This means that the pattern of increased difference in soil loss in T1 versus T2 and T4 together in later years (2000 to 2002) was statistically significant. This significance indicates that the effect of T2 and T4 on soil loss increased with time. One reason for the significant reduction in soil loss over time in these treatments could be that N-fixing plants progressively matured and became better able to hold soil and reduce its erosion from the field.

N-fixing plants had a highly significant impact in controlling soil loss when farming and fertilizer were present (T2 versus T4). When *Alnus* was replaced by *Indigofera* or vice versa, the soil loss was not significantly different in all studied years (1996 –

2002), suggesting that the two plant species have similar capacities in controlling soil loss. Significant effect of the plant species was observed in the presence of farming and fertilizer. Overall, in the seven-year study period, the soil loss from the control plot was significantly higher (>405 Mg·ha^{-1}) than in SALT plots (T2 = 44 Mg·ha^{-1} fertilized plot with *Alnus* hedgerows, and T4 = 63 Mg·ha^{-1} fertilized plot with *Indigofera* hedgerows). Hedgerows with a moderate amount of fertilizer conserved more than 9 times the soil than the traditional farming system. Additionally, an application of N-fixing tree biomass improves soil fertility and crop production (Das et al. 2010; Chhetri 2011; Manandhar et al. 2011). The annual rate of soil loss in fertilizer input and farmers' practice SALT plots (T2 and T4) ranged from 6.3–9.0 Mg·ha^{-1}·a^{-1} (see Fig. 2) compared to 6 Mg·ha^{-1}·a^{-1} (OECD 2008) soil loss from well-managed agricultural land, which indicates low risk for crop productivity. These results can be compared to a severe loss of 58 Mg·ha^{-1}·a^{-1} soil from the non-SALT plot suggesting that N-fixing plants were indeed an effective erosion control system. This study is in agreement with a study by Maskey (2003) at Paireni, Chitwan, Nepal, which estimated that the soil loss was reduced by 50%–70% under SALT plots compared to non-SALT plots. Thus, N-fixing hedgerow plants with moderate amounts of fertilizer input were promising options to reduce soil loss in farming systems in hills and mountains (Bhattarai et al. 2009; Lamichhane 2005, 2011). Hedgerows reduced surface runoff water volume and soil loss by 26%–60% and >97% on sloping land in China (Sun et al. 2008). Sudmeier–Rieux et al. (2011) reported that soil loss and run-off water are always serious problems in hillside agriculture systems because topsoil erosion leads to reduced crop production.

There was no significant effect of treatments (T2 and T3) on soil loss (Table 5A), indicating that the amount of external fertilizer input did not effectively reduced soil loss over time. This might be due to differences in farmer's practice in different years, such as more or less use of mulch. However, T2 was more effective than T3 in soil conservation throughout the study years, although the differences were not significant, indicating that moderate amounts of organic manure input helped to minimize soil erosion.

Table 5. Influence of (A) fertilizer input (T2 and T3) and (B) farmers practice (T2 and T5) on soil loss (One-way ANOVA results, 1996 – 2001).

Treatment	df, F value	Pr F
A. Effects of fertilizer (T2 and T3)	$F_{0.05(1), 1, 40}$ = 1.35	0.253
B. Effects of farmers practice (T2 and T5)	$F_{0.05(1), 1, 40}$ = 0.051	0.816

There was no significant effect of treatments (T2 and T5) on soil loss (see Table 5B) indicating that farmers' practice (T2) or its absence (T5) did not play significant role in controlling soil loss.

Soil loss was very high during 1998 (131 Mg·ha^{-1}) and 2001 (138 Mg·ha^{-1}) due to heavy rainfall and storms (higher intensity precipitation: 1947 mm in 2001) during monsoons, coarser-textured soil, and rain that fell immediately after tilling of soil. Intense monsoonal rainfall increases loss of fertile soil in hills

and mountain regions. Besides, soil erosion depends on several other factors such as vegetation cover, magnitude of precipitation, topography, climate, tectonics, and slope. These factors play dominant roles in soil erosion of mountain landscapes depending upon the catchment characteristics (Gabet et al. 2008). Therefore, soil restoration practices will increase soil fertility and hence, achieve greater food production for growing populations. Locally available leguminous shrubs provide high biomass production to enhance soil nutrient cycling and improve soil fertility, thereby increasing water retention in the soil (Sun et al. 2008). In the long run, hedgerows form bio-terraces by holding up the eroded soil on sloping land. Bio-terraces were formed within 3–5 years after SALT system establishment at Godawari, where the slope was initially 25°.

Effects of SALT models on maize yield

Treatments T1, T2 and T4 showed significant differences in maize yield (p <0.0001) (Table 6). Differences were due to the presence or absence and the species of hedgerow plants. A significant difference was also observed across years indicating natural variability in crop production created by N-fixing plants (p <0.0001). Pairwise comparison of treatments indicates that T2 and T4 significantly increased maize yield in all seven studied years (Fig. 3). Furthermore, pairwise comparison indicates the years that differed in maize production.

Table 6. Influence of N-fixing plants on crop production. Two-way ANOVA results with interaction for combinations of all levels of two main factors, year (1995–2001) and treatment (T1, T2 and T4).

Overall model $F_{20, 42}$ = 10.90, p < 0.0001, MSE = 371.45				
Source	DF	ANOVA MS	F Value	Pr F
Year	6	4093397.4	29.67	<0.0001
Treatment	2	1216589.7	8.82	0.0007
Year × Treatment	12	257667.2	1.87	0.0685

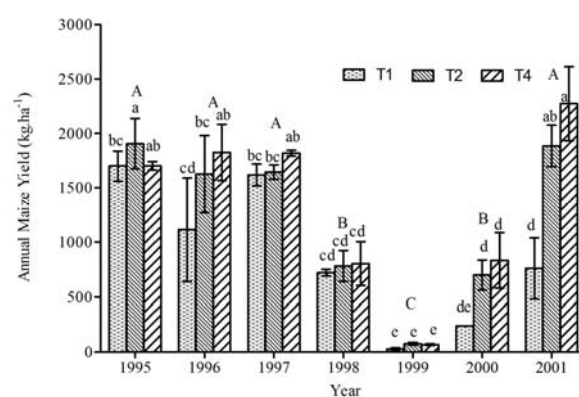**Fig. 3 Effect of N-fixing plants on maize yield when farmer practice and fertilizer were present (Mean ± SE, kg·ha^{-1}, n = 21) during 1995 – 2001.** Letters "a", "b", "c", "d" and "e" indicate statistically significant differences among treatments T1, T2 and T4. Letter "A", "B" and "C" indicate statistically significant differences among years (Two-way ANOVA, $F_{20, 42}$ = 10.90, p <0.0001, SNK multiple range test, α = 0.05).

The interaction between year and treatment was not statistically significant on maize yield (p = 0.067) (see Fig. 3). Crop production in T1 versus T2 and T4 were significantly different for 1998, 1999, and 2000 but not significant in other years. Part of the reason could be the predatory effects of birds, rabbits, deer, squirrels and other wildlife, but also poor germination. Because the study site was located in a forest patch, no fences were built to protect crops from animals (based on observation during study period and personal communication with ICIMOD field staff at Godawari). The increase in the maize yield from SALT plots T2 and T4 might be due to the physical barrier of hedgerows, which protected top fertile soils from erosion by flowing water and addition of organic mulch cut from hedgerows.

N-fixing plants significantly increased crop production when farmers' practice and fertilizer were present. When *Alnus* was replaced by *Indigofera* or vice versa, maize yield was not significantly different from year to year in all studied years (1995 – 2001), suggesting similar enhancement of crop yield by the two plant species.

An overall fertilizer effect on T2 and T3 significantly improved maize yield (p <0.0001) (Table 7). A significant difference was also observed across the years, indicating that external fertilizer is effective to enhance maize production over time (p < 0.0001). Pairwise comparison of treatments indicated increased maize yields in three years (1995, 1996 and 1997) in T2, which were significantly higher than in T3 (Fig. 4). Reasons may be that the foliage and twigs in N-fixing plants are rich in essential nutrients, and their root systems and associated bacteria help to recycle nutrients effectively (Maskey 2003). Also, nutrient availability from manure and mulch encourages growth of micorrhizae and other beneficial microorganisms that enhance crop yield (Das et al. 2010). Maize production was also significantly influenced by the interaction between year and treatment (p =0.0015) indicating that the temporal trend in maize yield was not similar between T2 and T3. This means that the trend of increased difference in crop production of both the year and the treatment was statistically significant (see Fig. 4).

The results showed that additional amounts of fertilizer input enhanced soil productivity by retaining organic matter. The reasons might be that N-fixing plants with moderate levels of external fertilizer input enhance water retention in T2. The reason for the decline of crop yield in 1999 was due to heavy loss of surface soil in the previous year (Figs. 3 and 4) due to high rainfall (2016 mm) and erosion of fertile soil. Moreover, the crops were damaged by wildlife (such as rabbits and deer), and poor germination. Therefore, the agricultural system needs to diversify to meet the demand for local food supply and people's livelihood. Although a hedgerow intercropping system is effective in controlling runoff water volume and soil erosion, resource competition between crops and hedgerows trees reduces crop production (Sun et al. 2008). These authors also reported that the depletion of soil nutrients, organic matter, and NPK exchange are negligible at soil depths >40 cm. Furthermore, fertilizer input increases through mulching, pruning, nutrient recycling, and infiltration during rainfall which consequently provides nutrients to plants during growing seasons and increases crop productivity.

Table 7. Effects of fertilizer on crop production. Two–way ANOVA results with interaction for combinations of all levels of two main factors, year (1995–2001) and treatment (T2 and T3).

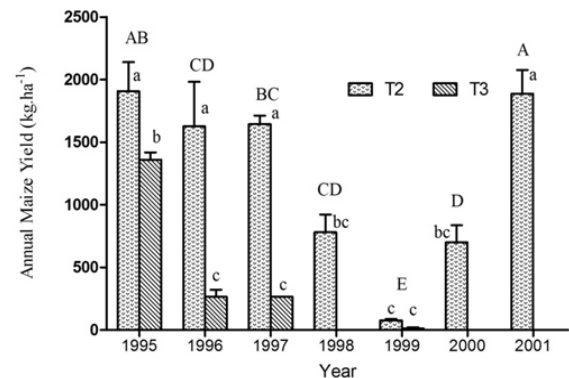| Overall model F = 17.42, p < 0.0001, MSE = 290.3				
Source	DF	ANOVA MS	F Value	Pr F
Year	6	1671331.7	19.83	<0.0001
Treatment	1	2720094.4	32.27	<0.0001
Year × Treatment	3	644697.6	7.65	0.0015

Fig. 4 Effect of fertilizer input on maize yield (Mean ± SE, kg·ha^{-1}, n= 21) between treatments during 1995–2001. Letters "a", "b" and "c" indicate statistically significant differences among treatments T2 and T3. Letters "A", "B", "C", "D" and "E" indicate statistically significant differences among years (Two-way ANOVA, $F_{13, 28}$ = 17.42, p <0.0001, SNK multiple range test, α = 0.05).

Effects of SALT models on soil properties

Soil samples (10–15 cm depth) were collected from all treatments to analyze the various soil parameters in June 2004. We used one-way ANOVA to test treatment effects at five levels and pairwise comparison to identify differences between T1 versus T2 and T4, T2 versus T3 and T2 versus T5. Pairwise comparison of treatments showed that T2 and T4 were significantly higher than T1 in moisture content, water holding capacity, pH, total nitrogen, available phosphorous, and available potassium (p <0.0001) but not in organic matter content or soil texture (Table 8) indicating that both N-fixing plants, *Alnus* and *Indigofera*, were equally capable of enhancing soil parameters. Fertilizer impact in T2 was found to be significantly higher than T3 on all studied soil parameters related to soil fertility, such as moisture content, water holding capacity, pH, organic matter content, total nitrogen, available phosphorous, available potassium, sand and clay (p <0.001) with the exception of silt content. Part of the reason could be N-fixing plants held additional nutrients because these plants were mature enough to reduce runoff water volume and soil loss. Furthermore, N-fixing plant roots also enhance soil retention.

To see the effects of farmers' practice on nutrient conservation, soil parameters between T2 and T5 were compared. Moisture

content, water holding capacity, organic matter, available phosphorous, available potassium, and sand were significantly different (p <0.001) but pH, total nitrogen, silt and clay were similar. This might be due to the shading effect of fruit trees in T5. This indicates that farmers' practice alone was not adequate to enhance soil organic matter and total nitrogen, which are integral to soil fertility. The soil texture was loamy and of fairly good quality (see Table 8). Percentages of sand, silt, and clay showed considerable variation in soil collected from different treatments. This might be due to poor growth of N-fixing hedgerows.

The addition of biomass to soil from pruning of hedgerows ultimately enhanced beneficial effects on the physical and chemical properties of soil. N-fixing plants retain soil moisture for a longer period because they tap nutrients from the lower layers of the soil and also provide shade to field crops, which lowers temperatures and modifies the microclimate beneath the canopy (Lamichhane 2011). One advantage of the tree-crop based cropping system is that trees extract nutrients from the lower horizon beyond the reach of the annual crops. Thus, the N-fixing plants are important for tapping water and nutrients that have leached from the surface into the subsurface. Normally, soil acidity increases with elevation, causing soil acidity problems (Farrell et al. 2011). Our results confirmed this trend with soil pH measurements of 4.0–5.0. The use of manure and SALT practices such as pruning might have contributed to maintain a moderately acidic soil pH, which was the optimum level for leguminous and vegetable crops (Lamichhane and Thakur 2004).

Table 8. Effects of sloping agricultural land technology on soil characteristics of Godawari mid-hills of Nepal.

Treatments	MC (%) n=6	WHC (%) n=6	pH n=6	OM (%) n=6	Total N (%) n=6	Av. P_2O_5 (kg·ha^{-1}) n=6	Av. K_2O (kg·ha^{-1}) n=6	Sand (%) n=3	Silt (%) n=3	Clay (%) n=3	Class
T1	24.9±0.57^a	53.3±0.42^a	4.8±0.08^a	4.8±0.05^a	0.26±0.00^a	237.1±0.79^a	197.6±0.41^a	41.4±1.82^a	40.5±1.52^a	18.1±1.13^a	loam
T2	31.8±0.22^b	62.3±0.28^b	5.6±0.05^b	5.3±0.11^b	0.29±0.01^b	282.2±1.20^b	331.5±0.60^b	33.3±0.86^b	44.6±1.37^a	22.1±0.53^a	loam
T4	32.3±0.52^b	60.0±0.44^c	5.4±0.03^b	5.4±0.16^b	0.31±0.00^b	329.6±2.50^d	326.3±1.06^d	37.01±1.20^{ab}	42.9±1.28^a	20.1±0.52^a	loam
T2	31.8±0.22^b	62.7±0.28^b	5.6±0.05^b	5.3±0.11^a	0.29±0.01^b	282.2±1.20^b	331.5±0.60^b	33.3±0.86^b	44.6±1.37^a	22.1±0.53^a	loam
T3	24.7±0.28^a	47.3±0.25^d	4.6±0.08^a	2.1±0.22^c	0.26±0.00^a	105.8±1.36^c	215.5±0.64^c	42.1±2.60^c	40.5±1.02^a	17.4±1.61^b	loam
T2	31.8±0.22^b	62.3±0.28^b	5.6±0.05^b	5.3±0.11^a	0.29±0.01^b	282.2±1.20^b	331.5±0.60^b	33.3±0.86^b	44.6±1.37^a	22.1±0.53^a	loam
T5	38.2±0.56^d	64.5±0.25^e	5.5±0.07^b	6.4±0.01^d	0.30±0.00^b	338.7±2.14^e	345.8±1.44^e	32.1±0.78^d	44.9±0.40^a	23.0±0.38^{ab}	loam

Soil samples from 10–15 cm depth were collected on June 2004. Soil parameters (Mean ± SE) with same letter are not significantly different among treatments (parametric one-way ANOVA, α = 0.05, p <0.0001). Column mean are separated by Tukey's multiple comparison test between T1 versus T2 and T4, T2 versus T3, and T2 versus T5 to see the treatment effects. MC= Moisture Content, WHC=Water Holding Capacity, OM=Organic Matter, Av.=Available.

Soil nutrient loss

Eroded soil samples were collected from all treatments in July 2004 to analyze the amount of organic matter and total nitrogen loss during precipitation. Organic matter content was significantly higher in T1 than in the treatments (p <0.0001) (Fig. 5A). However, different types of hedgerow plants did not exhibit any significant difference in organic matter loss (T2 and T4). Analysis showed that fertilizer input played a significantly greater role in conserving soil organic matter in T2 than T3. Also, a similar impact was observed for farmers' practice while comparing T2 and T5, indicating that hedgerows effectively controlled nutrient loss. However, total nitrogen loss was similar for all treatments in eroded soil (see Fig. 5B).

The highest amount of fertilizer input (OM and N) was lost through runoff on the non-SALT plot (control). When SALT treatment was applied with mulch, the pruned biomass maintained soil moisture levels for a longer period due to low evaporation from the soil. Both the above-ground (such as pruning and leaf litter) and the underground parts (such as fine root turnover and root residues) have an impact on organic matter and nutrient content in alley soil. Hedgerow systems maintained the production of annual crops, and the nitrogen and phosphorus supplied by pruning was unable to meet the requirements for maximum yields.
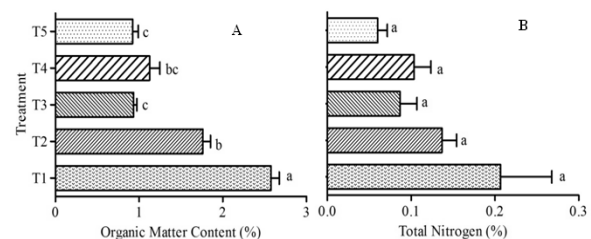

Fig. 5 Effect of sloping agricultural land technology on (A) soil organic matter loss (p <0.0001), and (B) total nitrogen loss (p <0.062) through eroded soil under different treatments. Same letters are not statistically significant different among treatments (Mean ± SE, n = 3, parametric one-way ANOVA, α = 0.05, Tukey's multiple comparison test).

External input (middle-level) of fertilizer was necessary to improve crop yields, as observed in T3 when various data on soil loss, maize yield, and soil nutrients were compared with other treatments. When manures were used as fertilizer, the rate of N-cycling increased significantly, whereas mulch increased soil moisture by reducing soil loss. Seasonal variations in organic matter and nitrogen levels play an important role in plant produc-

tivity (Farrel et al. 2011). Gami et al. (2009) showed that addition of moderate amounts of farmyard manure increased soil organic matter and total nitrogen availability, and increases crop productivity but improved soil quality was not achieved at landscape scale. Nandwa et al. (2011) proposed an integrative approach to increase economic output in developing countries through increased soil productivity and improved agricultural production, which are directly linked to food security and livelihoods of the poor. Sudmeier–Rieux et al. (2011) suggested that hill and mountain people adopt strategies to cope with the risks posed by geological, social and economical interactions caused by limited access to land resources and lack of scientific capabilities, and leading to concerns for food security and human health. Sharma et al. (2010) focused on the need of community-oriented ecosystem/landscape conservation policies for sustainable mountain development, which can be achieved through incorporation of issues posed by climate change, information sharing, and enhancing scientific understanding.

N-fixing plants (*Alnus nepalensis* and/or *Indigofera dosua*) has significant effects on reducing runoff water volume and controlling soil erosion, which resulted in improved crop productivity by enhancing soil nutrients, primarily NPK and organic matter. Hedgerows significantly lowered runoff by 38%–43% and soil loss by 72%–89% thus directly improving soil fertility in T2 and T4 compared to T1. Decreasing soil erosion was primarily attributed to the direct and indirect effect of conservation measures and to increases in soil organic matter and nitrogen resulting from the application of hedgerow trimmings and moderate inputs of fertilizer. Significant improvement in soil fertility was reflected in 72%–87% increases in maize yields in SALT treatments (T2 and T4) compared to traditional farming practice.

Conclusion

Hedgerow SALT systems adequately conserved soil and water, enriched soils, stabilized slopes, and enhanced farming. The SALT systems gradually formed bio-terraces. Organic matter and nutrient contents in soil were increased by adoption of green manuring, incorporation of legume crops and introduction of leguminous fodder species, and moderate inputs of external fertilizer. Therefore, SALT can be an ecologically suitable, economically sound, technologically simple, socially acceptable, and appropriate farming system on hills and mountain regions. SALT systems can be integrated to spatial patterns and landscape ecology that help achieve well-functioning ecosystems and aid development of lands for agricultural activity. However, researchers need long-term research and quality environmental data assistance to draw effective lessons to address the future scope of SALT systems.

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